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AIR FORCE RESEARCH LABORATORY ROBOTICS TECHNOLOGY DEMONSTRATION RANGE CLEARANCE OF UNEXPLODED ORDNANCE AT MASSACHUSETTS MILITARY RESERVATION

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14. ABSTRACT

The Air Force Research Laboratory (AFRL) Robotics Research and Development Team conducted a technology demonstration at the Massachusetts Military Reservation (MMR) from 24 March 2008 to 17 January 2009. This operation clearly demonstrated robotically controlled equipment was a safe and cost-effective method for remotely locating, removing, and neutralizing munitions and explosives of concern (MEC). These demonstrations cleared a total of 38.8 acres of vegetation from BA-1 Grenade Court, Central Impact Area (CIA), L Range, J-3 Range, nine firebreaks and widened two roads. This operation encompassed locating and removing hundreds of potential munitions items, removing approximately 12,103 pounds of scrap consisting of range related debris (RRD) and munitions debris (MD) located on L Range and sifting approximately 5,000 cubic yards of soil from J-1 Range Berms potentially containing UXOs.

15. SUBJECT TERMS

Massachusetts Military Reservation (MMR), clearance, Camp Edwards, subsurface ordnance, UXO, OCU, vegetation, munitions and explosives of concern (MEC), range related debris (RRD), munitions debris (MD), unmanned ground vehicles (UGV), EOD

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1.0 SUMMARY

The Air Force Research Laboratory (AFRL), Airbase Technologies Division, Robotics Research and Development Team conducted a technology demonstration at the Massachusetts Military Reservation (MMR) from 24 March 2008 to 17 January 2009. This operation clearly demonstrated robotically controlled equipment was a safe and cost-effective method for remotely locating, removing, and neutralizing munitions and explosives of concern (MEC). These demonstrations cleared a total of approximately 40 acres of vegetation from BA-1 Grenade Court, Central Impact Area (CIA), L Range, J-3 Range, nine firebreaks and two roads. This operation encompassed locating and removing hundreds of potential munitions items (**Table 1**), removing approximately 12,103 pounds of scrap consisting of range related debris (RRD) and munitions debris (MD) located on L Range and sifting approximately 5,000 cubic yards of soil from J-1 Range Berms potentially containing unexploded ordnance (UXO).

Table 1: Number and Types of Items Located and Removed at MMR

	L Range	CIA	Former K	Former A	J-1 Range Berms	TOTAL
20mm Projectiles		1	2			**3**
37 mm Projectiles		4		12		**16**
40mm Grenades (intact)	76					**76**
40mm Grenades (partial)	24					**24**
40mm Grenades (inert)			16			**16**
60mm Mortars		2				**2**
75mm Projectiles				1		**1**
81mm Mortars		25			8	**33**
83mm Rockets					1	**1**
105mm Projectiles		11			114	**125**
155mm Projectiles		11			4	**15**
3.5” Practice Rockets (inert)		1	115			**116**
5” Rockets		1				**1**
8” Projectiles					1	**1**
TOTAL	**100**	**56**	**133**	**13**	**128**	**430**

This technology demonstration was conducted over an 11-month period of time at seven separate locations: 1) Former A Range, 2) BA-1 Grenade Court, 3) Central Impact Area (CIA), 4) J-1 Range Berms, 5) J-3 Range, 6) Former K Range, and 7) L Range. Operation of remotely controlled unmanned ground vehicles (UGV) eliminated hazards associated with traditional methods of employing explosive ordnance disposal (EOD) personnel (**Figure 1**). Remotely controlled UGVs significantly reduced the risk to human life by increasing the stand-off distance where UXO can be located and neutralized.

Figure 1: Traditional UXO Detection Using EOD Personnel

The overall budget to clear the MMR of vegetation and UXO was between one and two million dollars. The AFRL Robotics Research and Development Team completed this mission for $1.1 million. Using the All-Purpose Remote Transport System (ARTS) AFRL Robotics personnel initially cleared approximately eight acres of vegetation at L Range in 11 days. This range contained high concentrations of UXO that would have made it very dangerous and costly to clear using traditional methods. **Figure 2** shows robots are more capable of expediently conducting these types of operations. UGVs, in only 11 days, cleared the same amount of vegetation two EOD technicians would have taken months to clear. The use of robotically controlled UGVs was also deemed a safe and expedient method to move MEC to a central location for detonation using the Department of Defense (DoD) consolidated shot program. This provided substantial cost savings as the cost of one blow in-place operation (BIP) is approximately $12,000, per detonation point including clean-up costs.

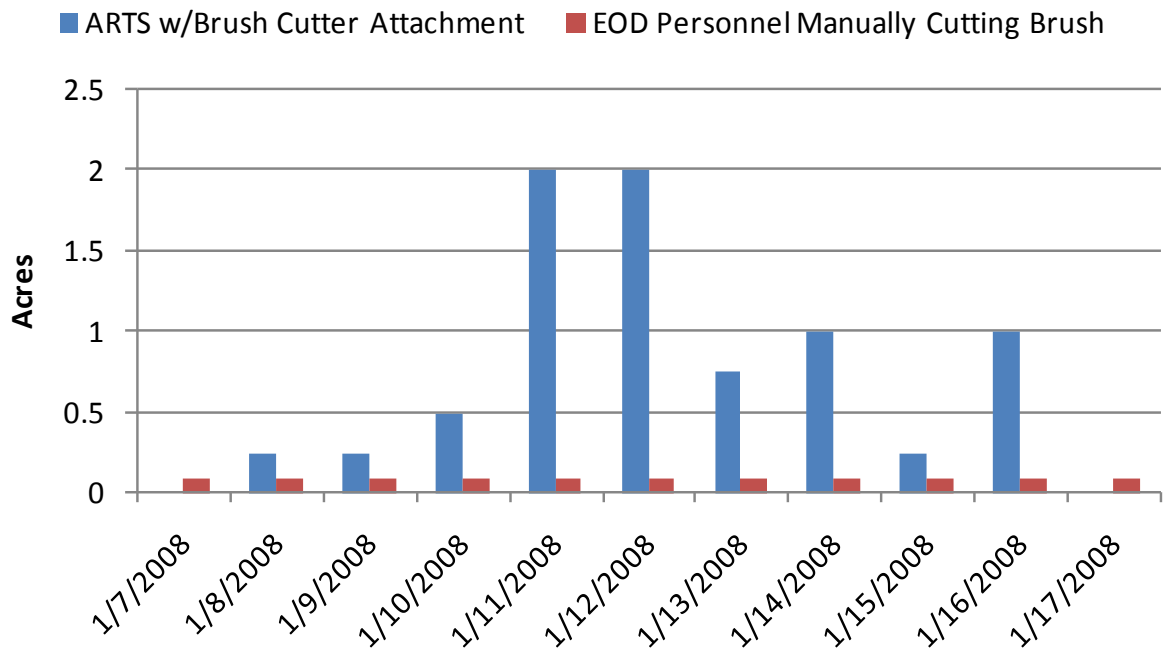

Figure 2: Acres of Vegetation Cleared Daily at L Range

2.0 INTRODUCTION

2.1 AFRL ROBOTICS BACKGROUND

The AFRL Robotics Research and Development Team has been involved with robotic automation research for approximately 22 years. The robotics mission to "conduct research and development of advanced robotic technologies and unmanned ground systems to protect, support, and augment the warfighter in the accomplishment of dirty, dull, dangerous, and impossible missions" is divided into five research areas: Advance Technologies Development, Integrated Base Defense Technologies (IBDT), Robotic EOD Technologies, Automated UXO Response Technologies (AURT), and Robotics for Airbase Operations and Support.

Following the tragic incident at Khobar Towers in June 1996, Air Force officials identified the need for the ability to safely remove or disable terrorist bombs. AFRL Robotics immediately responded by developing the ARTS technology, which can be used in critical real-world situations. ARTS provide a remote stand-off solution to operational needs to locate, remove, and neutralize UXO and improvised explosive devices (IEDs). The ARTS completed operational testing in December 1996 at Nellis Air Force Base (AFB), Nevada where it windrowed hundreds of Bomb Live Unit (BLU) 97A/B cluster munitions, withstanding six detonations. Even before the system could enter production, prototype ARTS with a 90mm water cannon (**Figure 3**) were deployed to Kuwait and Saudi Arabia for operational use.

Figure 3: ARTS with 90mm Water Cannon

AFRL Robotics conducted a project at Honey Lake, Sierra Army Depot, California to research robotic equipment and functional methods in the area of ordnance clearance. Several innovative robotic concepts were utilized during the Honey Lake operation: 1) night operations, 2) simultaneous robotic operations, and 3) extended operations. Extended periods of operation did not affect the performance of the UGVs, even with extreme environmental conditions such as 120ºF heat, heavy rain and sandstorms. During this eight week period of time, robotic systems removed an estimated 95,600 lb. of scrap materials from 19-grids (285 acres) with an average production rate of 1.02 acres per hour and a maximum rate of 1.86 acres/hour achieved. The robots operated for a total of 261 hours in 34 days. The use of robotic systems decreased the average time for manual clearance of each grid from 3 weeks to 1 week.

The robotics team retrofitted the Danish Hydrema 910 (Mine Clearance Vehicle) MCV-2 Flail System to be controlled remotely (**Figure 4**) and re-designated the vehicle as Mine Area Clearance Equipment (MACE). This development was in response to HQ Air Combat Command (ACC) Civil Engineering (CE), whom had expressed strong interest in being able to remotely employ the vehicle system, thereby removing the man-in-the-seat during mass area clearance operations to improve personnel safety.

Figure 4: MACE with Remote Control Operation

AFRL Robotics developed and demonstrated a proof-of-concept robotic perimeter system for the USAF Force Protection Battlelab. These units were developed for the Remote Detection, Challenge, and Response (REDCAR) project, which evaluated the utility of mobile robotics systems for installation security missions. AFRL developed a high-speed ground robotic system (SCOUT) and integrated existing robotic platforms (MDARS-E and Packbot) with the USAF Integrated Defense Security System (IBDSS). Several innovative concepts were demonstrated during this project including: high speed robotic operations (40 mph), weaponized robotic systems, common command and control using the Joint Architecture for Unmanned Systems (JAUS), and an Extensible Markup Language (XML) link with the Intelligence Database Support System (IDSS). Several mission specific payloads were evaluated including: reconnaissance, surveillance, and target acquisition (RSTA) systems, obstacle detection sensors, voice translation system, and lethal and non-lethal weapons systems.

2.2 Range Clearance of UXO

Munitions and ranges are essential to the DoD's missions, readiness, and arming and training our Nation's military forces. The public and regulatory agencies are expressing increased environmental and explosives safety concerns with munitions used at our ranges. Munitions that do not function or fully detonate as designed create UXO, which challenges both the sustainment of ranges and the eventual reuse of the land by the public.

Decades of military training, exercises, and testing of weapons systems has required we begin to focus our response on the challenges of UXO. Land acreage potentially containing UXO has grown to include active military sites and land transferring or transferred for private use such as Base Realignment and Closure (BRAC) sites and Formerly Used Defense Sites (FUDS). DoD responsibilities include: protecting personnel and the public from explosive safety hazards; UXO site cleanup project management; ensuring compliance with federal, state, and local laws and environmental regulations; assumption of liability; and appropriate interactions with the public.

Congress requested the DoD complete an estimate of the current and projected costs for UXO remediation and identify its plans for UXO remediation technology in support of this requirement in order to further close this information gap, using the April 1998 Defense Science Force Task Force Report on UXO Clearance and Remediation as the baseline. DoD's initial baseline estimate for UXO remediation costs range between $106.9 billion and $391 billion in 2001 year dollars. This estimate accounts for the complexity and variability of individual site conditions associated with range response activities. Indeed, the cost model required that known site specific data be combined with general conservative assumptions. [1]

2.3 MASSACHUSETTS MILITARY RESERVATION (MMR)

The Impact Area Groundwater Study Program (IAGWSP) is remedying groundwater contamination and its sources at Camp Edwards on MMR. These efforts are designed to protect public health and safety, and to restore the aquifer that is a source of drinking water for the four towns located on the upper portion of Cape Cod, Massachusetts.

Managed by the Army Environmental Command, the IAGWSP was initiated by the National Guard Bureau in 1996 to investigate possible areas of groundwater and soil contamination on base. Currently, the program is transitioning from investigation to cleanup with the initiation of several proposed interim cleanup actions. These actions will address one of the main areas of groundwater contamination by treating up to one-half million gallons of groundwater a day. They also will include the removal and treatment of approximately 30,000 tons of contaminated or potentially contaminated soil that may be contributing to groundwater contamination. Previous interim actions cleaned 1,800 tons of contaminated soil, removed metal from 6,200 tons of soil and rock, and extracted 50 tons of lead, which formerly was used on the firing ranges.[2]

2.3.1 Former A Range

The Former A Range was originally constructed in 1941 and functioned as an anti-tank artillery and rocket training site up until the 1960s. Tank targets were placed on specially designed rail cars and rolled on tracks, via gravity, downhill through two sets of switchbacks traversing a target area. There appear to be two primary target areas located where the rolling targets would be perpendicular to the firing direction, and presumably where trainees were trying to hit the target cars. At each primary target area, a soil berm was present in front of the tracks and a soil backstop was behind the tracks. Trainees would fire in an easterly direction at moving targets from gun positions at a firing point located 2,400 feet to the west of the target areas. The target rail cars would roll downhill to a platform at the bottom of the hill and then be loaded onto trucks and hauled to the top of the hill and returned to the tracks. Between the 1960s and mid-1970s, the range was converted to a machine gun training range. The layout of the range for machine gun training is unclear. Trainees may have fired on both static and moving targets in a manner similar to earlier artillery and rocket training.

Since 1998, there have been several investigations to assess the distribution of MEC at Former A Range. Investigations have included multiple ground-based electromagnetic surveys and subsequent anomaly investigation via hand digging by UXO technicians. MEC items have been found throughout the limits of the range, but are particularly dense in the primary target areas. Training records and items recovered during investigation activities indicate munitions and ordnance types present on Former A Range include: 37mm armor piercing (AP) and high explosive (HE) rounds, 40mm AP and HE rounds, 57mm AP rounds, 60mm mortars, 75mm HE and shot rounds, 81mm mortars, 90mm anti-aircraft rounds, 105mm artillery rounds, 3.5-inch rockets, .50 caliber ball and tracer rounds, and smoke grenades. Numerous MEC items (37mm, 40mm and 57mm) have required BIP operations. Some recent MEC investigations focused on assessing how much MEC has penetrated into the hillside in primary target areas. This work consisted of UXO clearance and soil excavation at three trench locations. The UXO clearance work was performed by the traditional method of UXO technicians' hand digging through soil to locate UXO items. Results of the recent investigations show most of the MEC items have not penetrated the hillside more than two feet. The UXO items of most concern at Former A Range are the 37 mm and 40 mm projectiles that are more likely explosive rounds. Most of the larger size UXO items recovered have been non-explosive filled rounds.

2.3.2 BA-1 Grenade Court

The BA-1 Grenade Court is an area of approximately two acres suspected of being used for practice and possibly live grenade training. The area was heavily vegetated and contained five concrete bunkers (**Figure 5**).

Figure 5: Bunker at BA-1 Grenada Court

2.3.3 Central Impact Area (CIA)

The CIA is a 330-acre portion of the Impact Area (**Figure 6**) where approximately 100 targets were located. These targets were fired upon from as many as 37 positions located along the perimeter of the Impact Area. The CIA was used as an impact area for artillery and mortars from the late 1930s until 1997. These munitions included High Explosives charges designed to explode on impact, inert practice rounds, and pyrotechnic rounds. Explosive fillers contained in some of these munitions are considered to be the ultimate source of groundwater contamination originating in the CIA. Specific fillers found in munitions at the CIA include TNT, Composition B, and black powder.

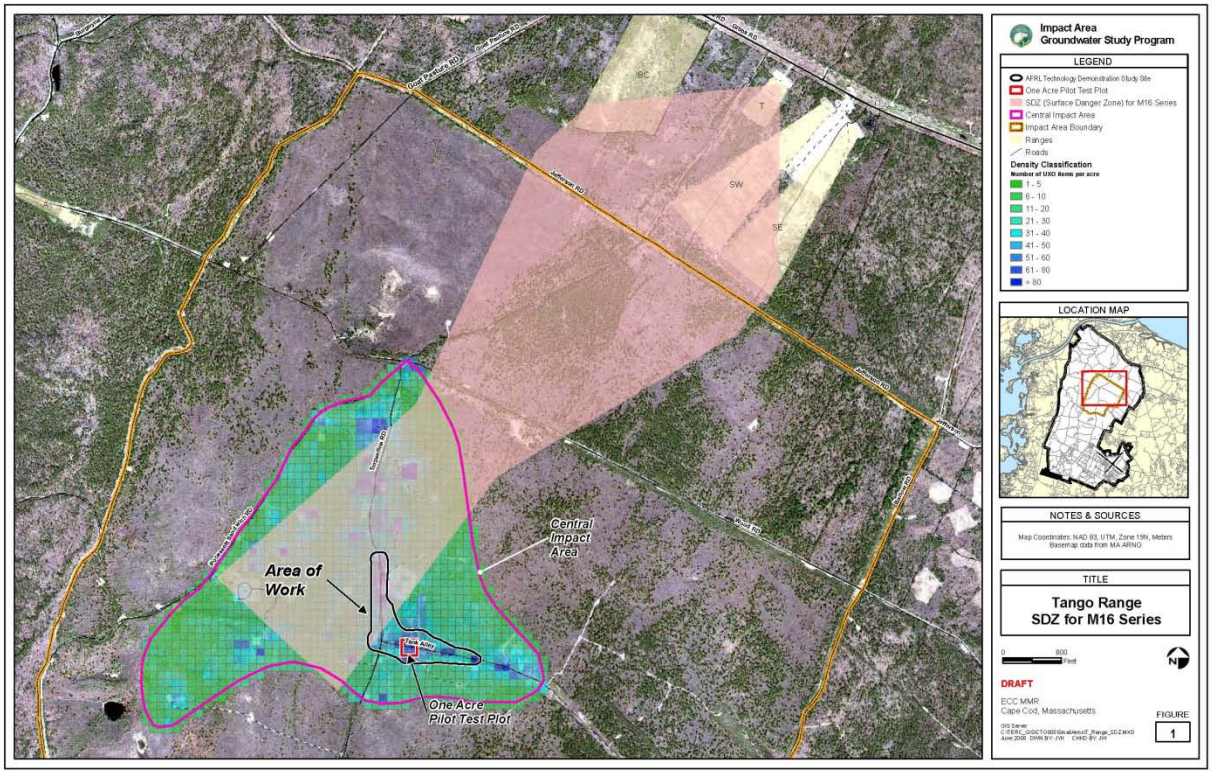

Figure 6: CIA Site Map

2.3.4 J-1 Range Berms

The J-1 Range (**Figure 7**) was operated by a series of munitions testing contractors, whose activities were based primarily on various contracts with Picatinny Arsenal. Most of the testing associated with the 1,000 meter and 2,000 meter impact berms involved the use of various types of 105mm rounds. Reportedly, most were inert practice rounds, but some High Explosive Anti-Tank (HEAT) rounds and discarding sabot rounds (either steel or tungsten) were also fired there. The rounds typically were fired from a bunker, through either of two “tunnel berms” located approximately 250 or 650 meters down range, into the 1,000 meter or 2,000 meter (A and B) impact berms. The tunnel berms were there to prevent off-target shots from going long or off post. The 150 meter berm was used for short range testing.

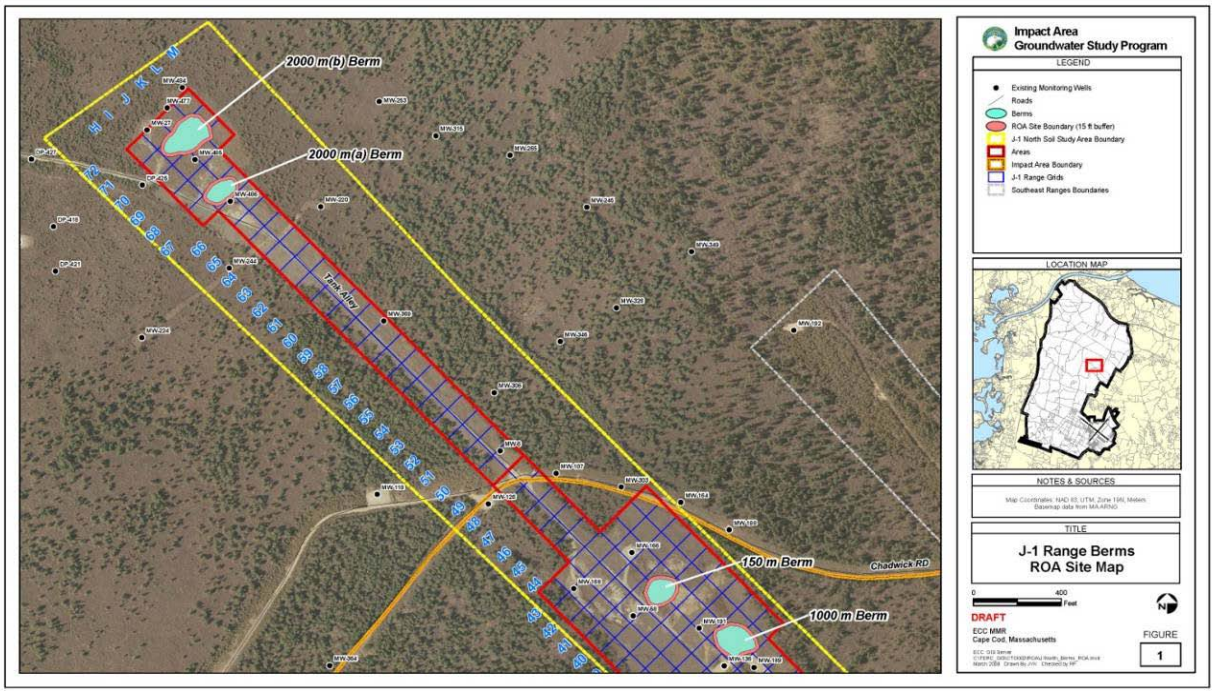

Figure 7: J-1 Range Berms Site Map

The impact berms typically were faced with steel armor plates, including side plates angled to channel the rounds to the center and down to the ground. The number of rounds fired at the impact berms is unknown. However, it has been estimated that approximately 39,000 rounds were fired into the impact berms during the course of a single 1.5-year contract. The number and types of rounds that may remain embedded within the berms is unknown.

2.3.5 J-3 Range

The area comprising the J-3 Range was initially developed between 1935 and 1941 as a training range for the firing of mortars and rockets. Starting in late 1960s, through the mid 1990s, portions of the range were used for contractor munitions testing. The northwestern portion of J-3 Range, known as the Barrage Rocket impact area, likely was not affected by testing activities. However, based on visible cratering and previous HE MEC finds, it apparently was a munitions impact area during training activities and still contains numerous, uninvestigated geophysical anomalies. The specific items anticipated in the area include the 4.5-inch Barrage Rockets and 81mm mortars.

2.3.6 Former K Range

The Former K Range is an inactive rocket and rifle grenade training range constructed in 1960 on the Western side of Greenway Road, south of Wood Road. Records indicate the range was used between 1960 and 1967 as a 3.5-inch HE rocket range. In 1968, the range was converted to a M79 grenade launcher range where, until the early 1970s, 40mm HE and practice grenades were used. During this time period the range was configured with ten firing points and several targets at variable distances downrange.

Sometime after the mid-1960s, the northern portion of the range fan was extended down-range 2,000 meters to a new target located on the north side of Wood Road. Little information is available on the historic use of this modified range; however, based on the layout, it likely was used for man-portable missile training. After the 1970s, the eastern end of the Former K Range was converted to a pistol range and renamed the P Range, the current designation of the range.

2.3.7 L Range

Range records and site reconnaissance indicate the L Range was used predominantly to train soldiers in the use of M203 and M79 type 40mm grenade launchers. Although the munitions found at the range included both practice and HE rounds, records indicate a large majority of the items fired were practice rounds that do not contain explosives. Information from historical records, aerial photographs, field observations and the air magnetometer surveys denote the presence of ten target locations and a firing line. The M203 and M79 type grenade launchers employ a pop-up sight that typically results in a large majority of initial firings falling short of their respective target. Ballistic corrections are then applied to bring subsequent firings onto the target. As a result, the MEC density was expected to be greatest in front of the targets.

2.4 TECHNOLOGY DEMONSTRATION

AFRL Robotics was contacted by the US Army Corps of Engineers (USACE) on behalf of the IAGWSP to demonstrate use of robotically controlled equipment to clear vegetation from a number of the firing ranges on MMR and perform subsurface ordnance location and clearance. Over an 11-month period of time, they successfully demonstrated the use of various types of UGVs to conduct these types of operations (**Figure 8**).

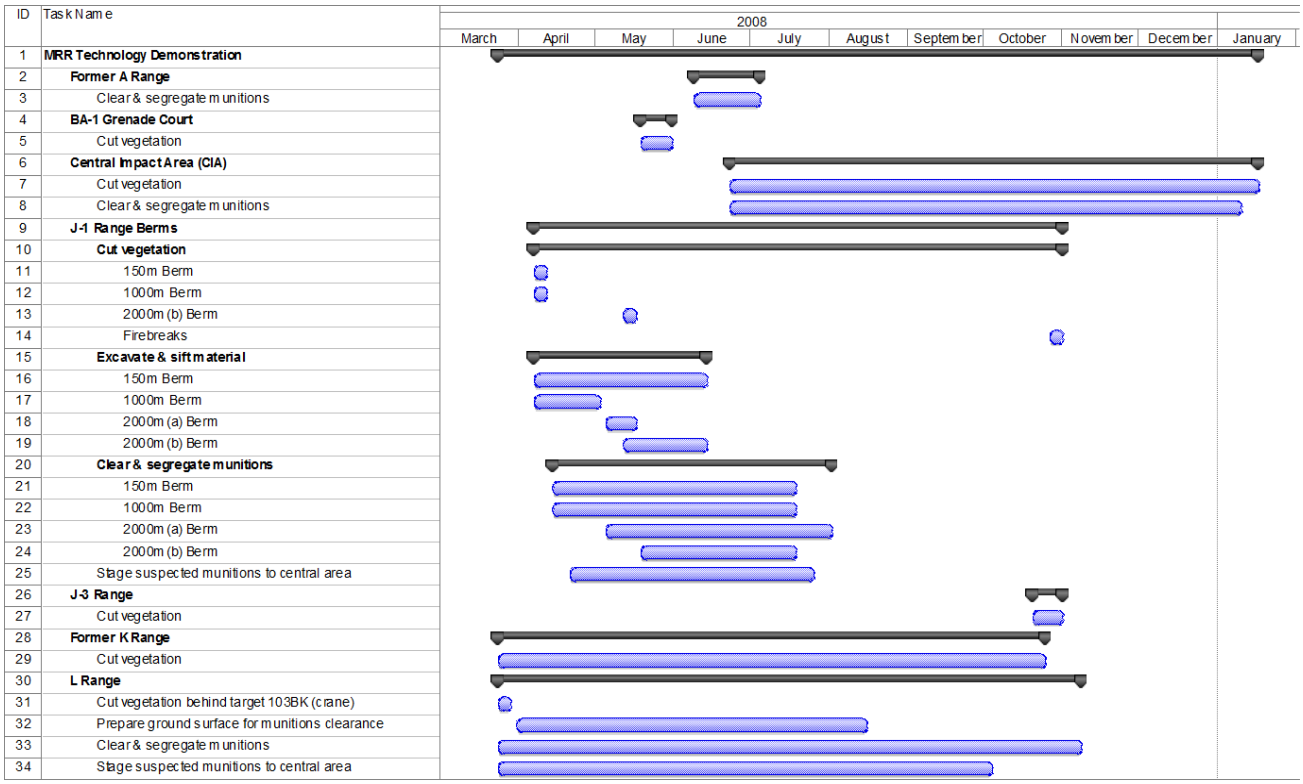

Figure 8: MMR Technology Demonstration Schedule

3.0 METHODS, ASSUMPTIONS, AND PROCEDURES

3.1 METHODS

The use of robotically controlled equipment to cut vegetation from unused firing ranges for the purpose of clearing and collecting MEC was demonstrated at MMR. AFRL Robotics personnel were in close contact with the USACE during this entire operation. Progress was measured by the amount of acres cleared of vegetation, the cubic yards of dirt sifted and the number of munitions items found and destroyed in a safe and cost effective manner. Conducting these operations without personnel injury or loss of life was the first metric for success. The second metric was cost saving. These types of operations typically are very expensive, costing millions of dollars. The third metric was a reduction in the amount of time required to clear these kinds of ranges. Range clearance normally takes years to accomplish because of the danger in locating and removing buried UXO.

3.2 ASSUMPTIONS

There were a number of assumptions made for the purpose of this report. The use of remotely controlled UGVs to conduct subsurface ordnance removal is safer than the traditional method of employing EOD personnel. In a typical range clearance operation, EOD personnel deploy in teams consisting of at least two individuals to first clear the range of vegetation using chainsaws and handheld brush-cutters. This is extremely hazardous work as the vegetation can conceal potentially dangerous munitions. Using robotically controlled equipment to conduct these operations is more cost effective than touch-labor. The nature of these operations requires a significant period of time to fully clear an unused range. For example, two EOD technicians could clear 1/10 of an acre (54ft x 80ft) per day. The old adage “time is money” could not be more true than in this scenario. Using men who require frequent breaks in extreme environmental conditions can be very costly.

3.3 PROCEDURES

This research operation used a number of different types of UGVs to determine the most expedient and cost effective method for conducting these types of operations. All equipment was robotically controlled from a mobile command center to ensure operator safety. The demonstration was conducted using a six day work week during all types of inclement weather.

AFRL Robotics personnel used the ARTS with a brush cutter attachment (**Figure 9**) to flush cut the vegetation within the technology demonstration areas and the ARTS configured with a tree shear attachment (**Figure 10**) to remove the oversized trees.

Figure 9: ARTS with Brush Cutter Attachment

Figure 10: ARTS with Tree Shear Attachment

The remotely operated Caterpillar (CAT) 325 excavator with sifter bucket (**Figure 11**) and electromagnet with thumb attachment (**Figure 12**) were used to locate and clear potential munitions items in very specific areas.

Figure 11: CAT 325 Excavator with Sifter Bucket

Figure 12: CAT 325 Excavator with Electromagnet and Thumb Attachment

MEC clearance was accomplished in the larger demonstration areas using the ARTS with power rake or rotor-tiller attachment (**Figure 13**) and ARTS with Cherrington Beach Cleaner attachment (**Figure 14**).

Figure 13: ARTS with Rotor-Tiller Attachment

Figure 14: ARTS with Cherrington Beach Cleaner

3.3.1 Risk Assessment

The risk assessment for clearing firing ranges of UXO is high: Catastrophic hazard severity category with an Occasional hazard probability (**Table 2**). The catastrophic risk of loss of life to EOD personnel manually conducting these operations is one of the primary reasons for using robotically controlled UGVs.

Table 2: Example Risk Assessment Matrix

	HAZARD SEVERITY CATEGORY			
	Catastrophic	*Critical*	*Marginal*	*Negligible*
HAZARD PROBABILITY	Death or system/ facility loss	Severe injury, occupational illness, or major system/ facility damage	Minor injury, minor occupational illness, or minor system/ facility damage	Less than minor injury occupational illness or system/ facility damage
FREQUENT *Likely to occur frequently **Continuously experienced	1	3	6	10
PROBABLE *Will occur several times **Will occur frequently	2	5	9	14
OCCASIONAL *Likely to occur sometime **Will occur several times	4	8	13	17
REMOTE *Unlikely, but possible to occur **Unlikely, but can be reasonably expected to occur	7	12	16	19
IMPROBABLE *So unlikely, assume it may not occur **Unlikely to occur but possible	11	15	18	20

*Specific Individual Item
**Fleet or Inventory

Low risk: Experiments that present no greater risk to personnel, equipment, or property than normal operations after appropriate controls have been applied – green.

Medium risk: Experiments that present a greater risk to personnel, equipment, or property than normal operations even after the appropriate controls have been applied – yellow.

High risk: Experiments that present a significant risk to personnel, equipment, or property even after all precautionary measures have been taken – red.

4.0 RESULTS AND DISCUSSION

Using remotely controlled UGVs, AFRL Robotics personnel cleared approximately 430 munitions items during this 11-month technology demonstration (**Figure 15**). All operations were completed safely, without injury to personnel, in a cost effective manner.

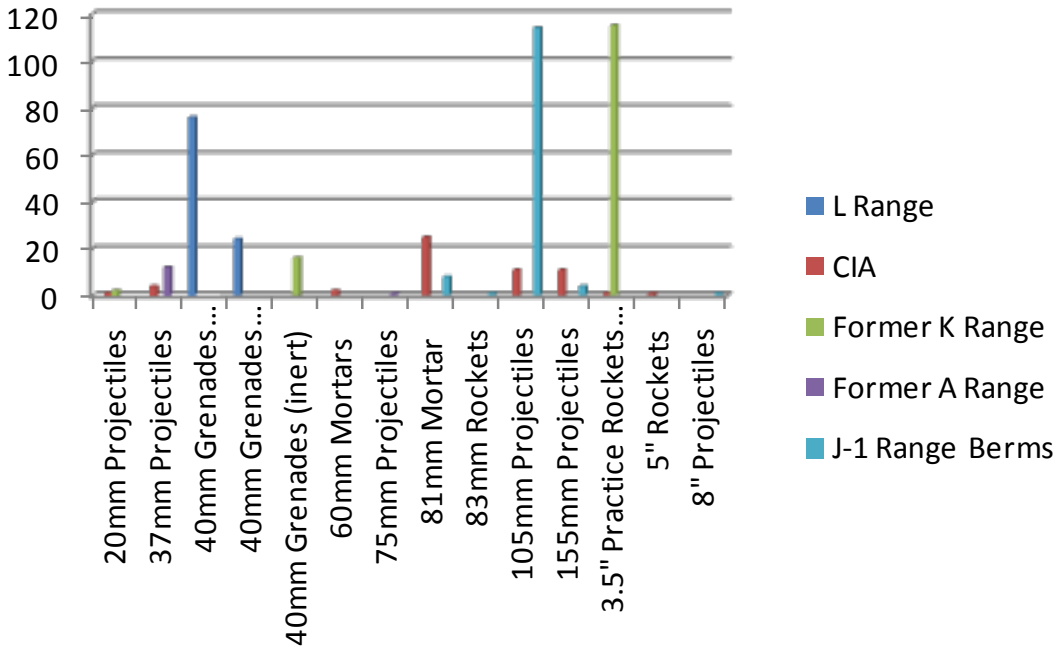

Figure 15: Types and Quantities of Items Found at Each Area

4.1 FORMER A RANGE

AFRL Robotics personnel performed MEC clearance (.25 acres) using the C325 excavator with an electromagnet attachment (**Figure 12**). Items removed by the magnet were inspected to distinguish MEC items from other benign materials. 12ea 37mm projectiles (possible HE) and 1ea 75mm projectile (possible HE) were found and destroyed (**Figure 16**). As is evident from **Figure 17** there is still a significant amount of remediation that needs to occur.

Figure 16: Items Collected with Magnet

Army personnel were able to implement standard procedures for consolidated shots as stipulated by the USACE since robotically controlled UGVs were available. These procedures offered significant savings over traditional BIP operations, which cost $12,000 per shot, including clean-up costs.

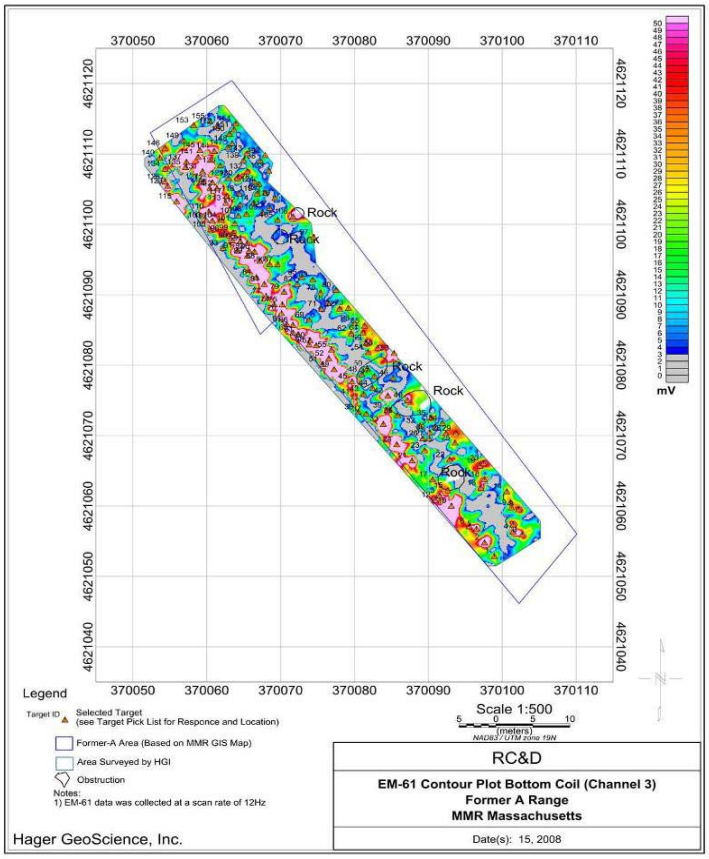

Figure 17: EM-61 Survey of Former A Range

4.2 BA-1 Grenade Court

Vegetation was cut within a 250 by 350 foot area (two acres) at the Grenade Range. Vegetation was cut flush with the ground surface using the ARTS with a brush cutter attachment and tree shear attachment (**Figure 9** and **Figure 10**). The cut vegetation was consolidated in one area of the site, using the ARTS with grapple bucket attachment (**Figure 18**), and chipped or removed from the site to accommodate future equipment. The woodchips were spread over the site after the completion of vegetation clearance. The vegetation clearance was needed to determine the number of anomalies with the potential to be UXO at the Grenade Court, which is fairly significant in a number of areas (**Figure 19**).

Figure 18: ARTS with Grapple Bucket Attachment

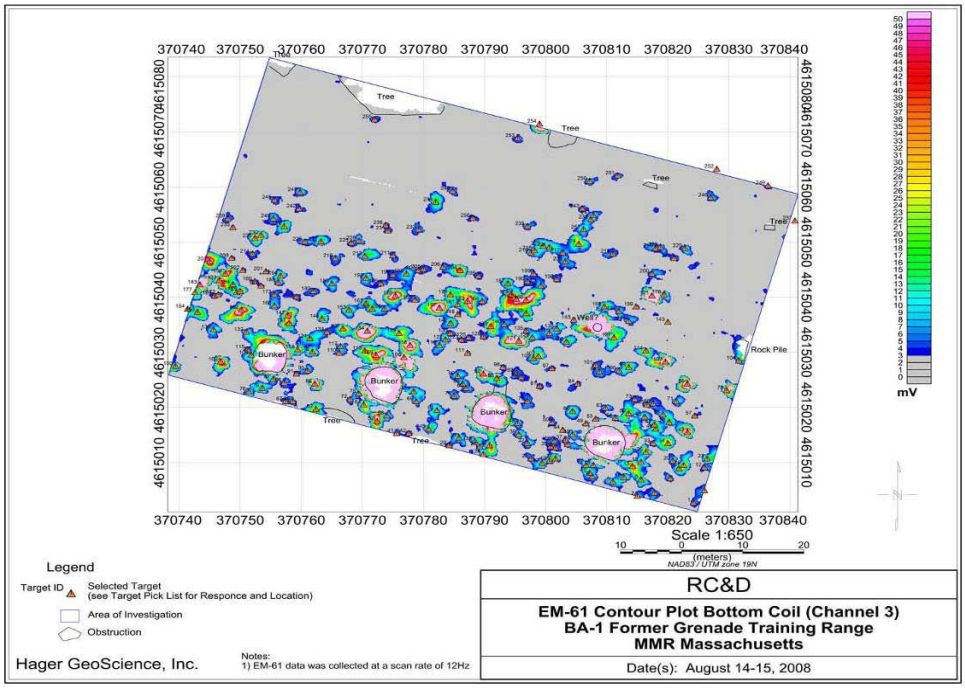

Figure 19: EM-61 Survey of BA-1 Grenade Court

4.3 CENTRAL IMPACT AREA (CIA)

Source removal in CIA (clearance of munitions and excavation of contaminated soil) was difficult due to dense vegetation; uneven terrain; and the variety, type, and high density of munitions and munitions debris located on and below the surface. AFRL flush cut 18 acres of vegetation using the CAT 325 excavator with Brontosaurus attachment (**Figure 20**), as part of the ongoing vegetation clearance and UXO surface clearance demonstration (**Figure 21**). This reduced the amount of material to manage during source removal.

Figure 20: CAT 325 Excavator with Brontosaurus Attachment

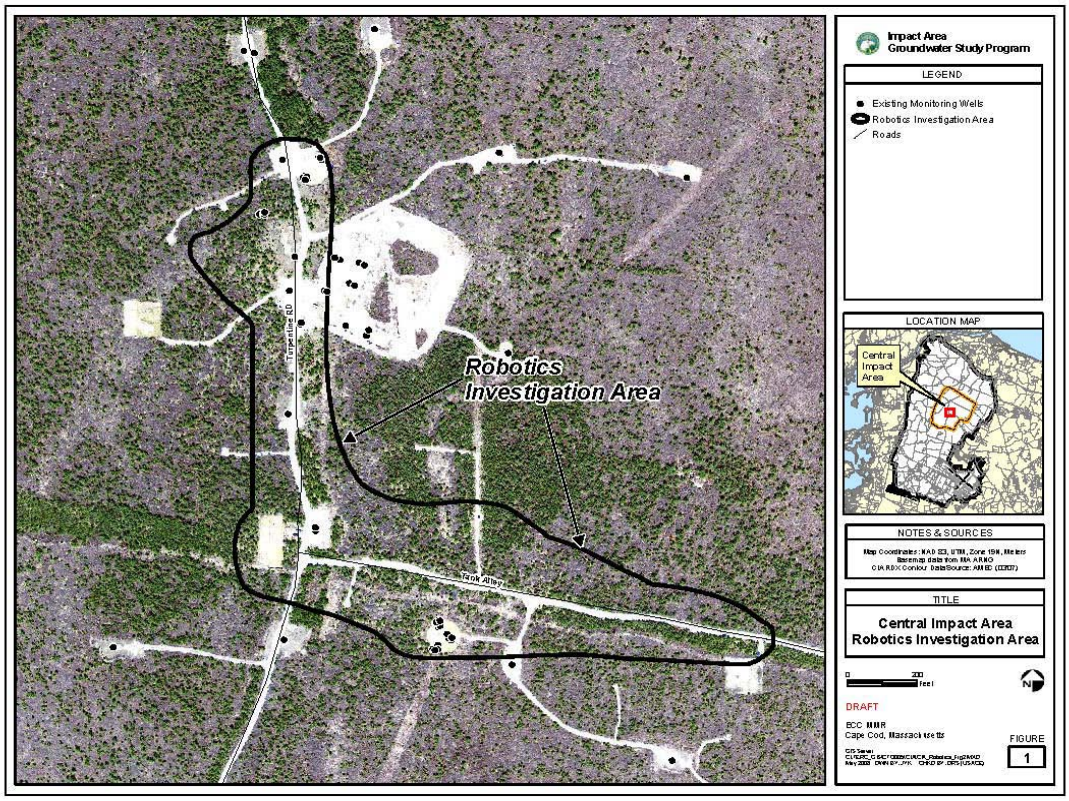

Figure 21: 18-Acre Area in CIA Cleared of Vegetation

4.4 J-1 RANGE BERMS

The remotely operated ARTS with brush cutter attachment (**Figure 9**) was used to clear two acres of vegetation on and in the vicinity of the four impact berms. After the brush was cleared, the remotely operated C325 excavator with sifter bucket attachment (**Figure 11**) was used to excavate and separate soil from oversize material such as RRD, MD and MEC from the front side of the four impact berms. The sifted soil was stockpiled adjacent to the berms and characterized in accordance with existing sampling protocols to determine final disposition (onsite re-use or offsite disposal). The oversize material was also stockpiled adjacent to the berms and sorted and inspected by UXO qualified personnel. Material was excavated from the berms until a determination was made that either: 1) no more scrap or MEC remains, 2) the available equipment is unable to continue operations efficiently, or 3) the site UXO safety officer determined that continued operations were unsafe. Using robotically controlled equipment, AFRL personnel cleared various types of munitions items (**Table 1)**.

4.5 J-3 RANGE

AFRL cleared the vegetation from two ¼ acre grids using the remotely operated ARTS with brush cutting and tree shear attachments (**Figure 9** and **Figure 10**) to accommodate proposed visual inspections, UXO surface clearance, geophysical surveys and follow-on intrusive investigations.

4.6 FORMER K RANGE

Investigation activities have included airborne and ground based geophysical surveys, and intrusive investigations to search for subsurface munitions and munitions disposal sites. The ground-based surveys were performed within the range target area at presumed target locations B, C, D and F (**Figure 22**). The survey and excavation results indicated that locations B and E were likely range target sites, based on the discovery of 3.5-inch rocket motors, 40mm grenades, associated fragmentation, and 55 gallon drums. Location C was determined not to be a former target site, and though the results were inconclusive, location F likely was not used extensively as a target site. In addition to these investigations, extensive groundwater and soil investigations have been performed.

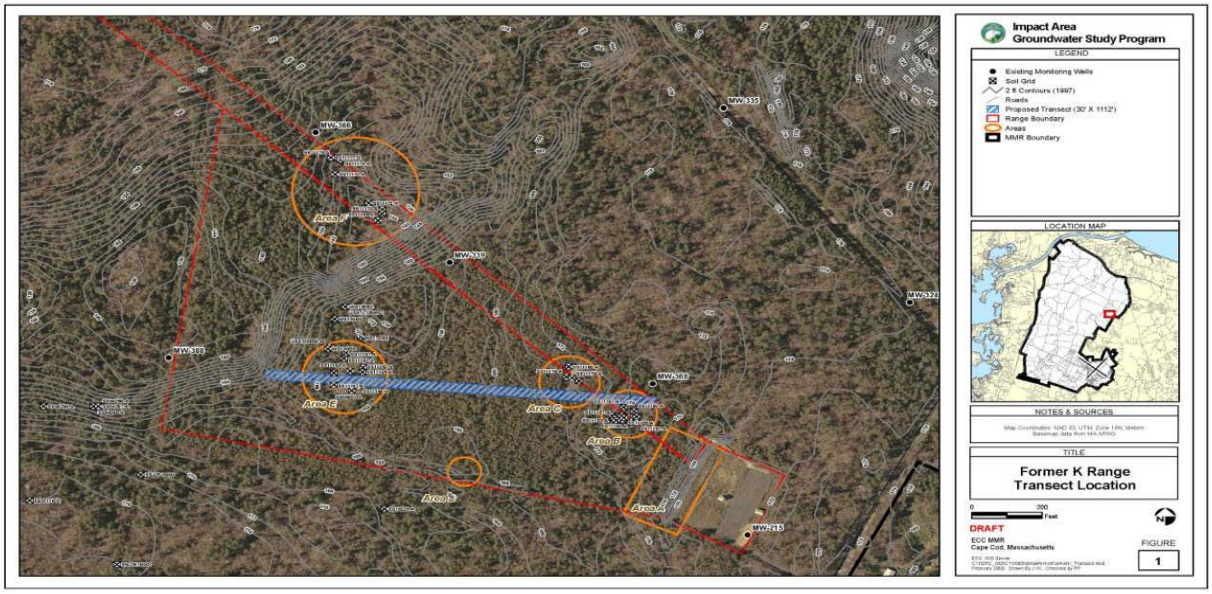

Figure 22: Former K Range Transect Locations

The vegetation within the down-range portion of the Former K Range is dominated by scrub oak mixed with pitch pine and hardwood trees. Therefore, to accommodate future visual inspections, potential ground-based geophysical surveys and intrusive investigations for determining MEC density within and outside of the range target areas, AFRL conducted vegetation clearing operations. All vegetation within a 30' wide by approximately 1,100' long transect (.75 acres) traversing target areas B, C and E and extending from near the firing positions in the front of the range to the back of the range were cleared. The vegetation was cleared using the ARTS with brush cutter attachment (**Figure 9**). Based on the successful results, geophysical surveys and intrusive investigations may also be performed using AFRL's remotely operated equipment. The findings will be used for evaluating MEC density (**Figure 23**) and the need for additional fieldwork at the Former K Range.

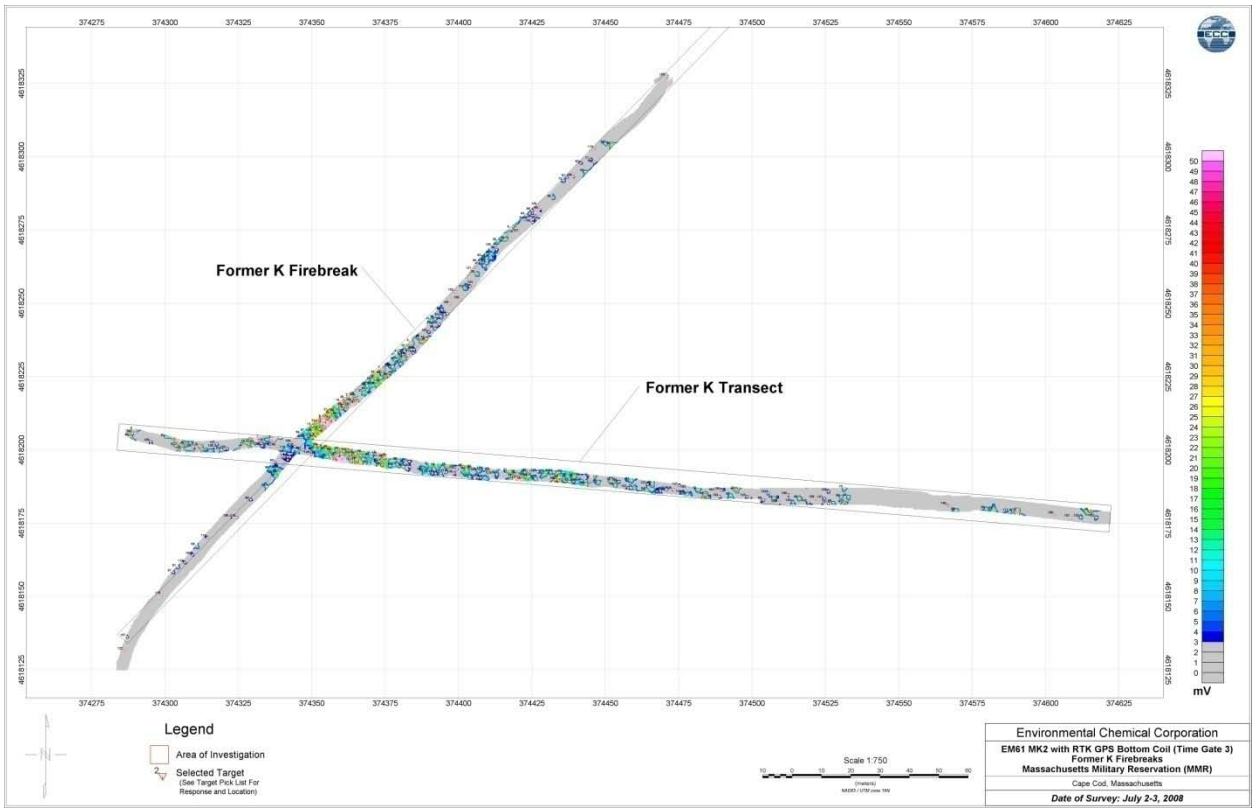

Figure 23: EM-61 Survey of Former K Range

4.7 L RANGE

From 07-18 January 2008, AFRL Robotics personnel cleared the vegetation from approximately eight acres of L Range, where the majority of MEC items were believed to exist, using remotely operated ARTS with brush cutting and tree shear attachments (**Figure 9** and **Figure 10**). During the next eight months, 100 potential munitions items (40mm grenades) were safely located and removed using remotely operated robotic equipment. The ARTS was found to be very effective in the excavation and removal of these munitions (**Figure 25**) and all MEC was managed in accordance with the established DoD Explosive Safety Board (DDESB) consolidated shot procedure. Using robotically controlled equipment, AFRL personnel cleared 12,103 lb. of scrap (**Figure 24**).

Figure 24: L Range Munitions and Range Debris

To accomplish MEC clearance, a power rake or rotor-tiller attached to an ARTS platform (**Figure 13**) was used to loosen the top layer of soil. After the soil was loosened an ARTS with Cherrington Beach Cleaner (**Figure 14**) was used to collect material greater than one inch in diameter (including 40mm grenades) from the top six inches of soil. Material collected by the ARTS attachments was brought to a processing area within the L Range for sorting and inspection by UXO qualified personnel.

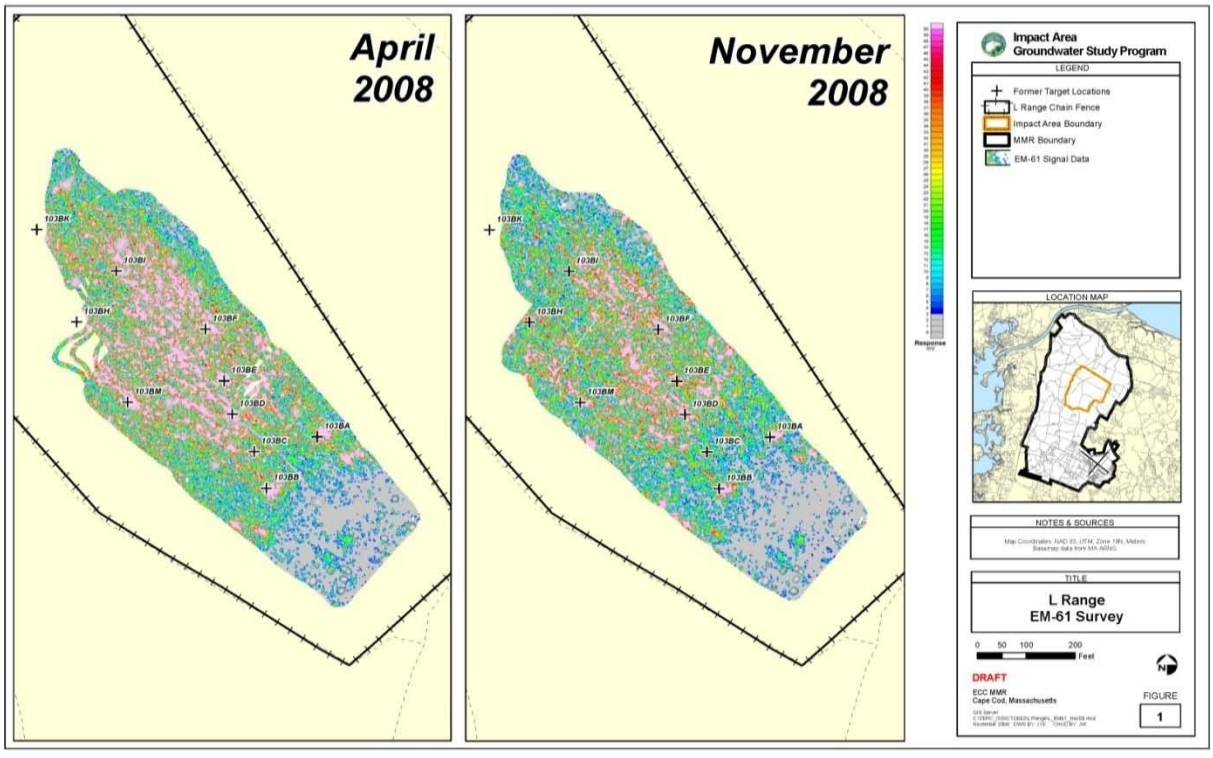

Figure 25: L Range Before and After Munitions Removal

5.0 CONCLUSIONS

Robotically controlled UGVs are a safe and cost effective way to remove and neutralize UXO on former firing ranges. Over an 11-month period of time, AFRL Robotics personnel demonstrated multiple pieces of equipment by: clearing approximately 40 acres of vegetation, locating and removing 430 potential munitions items, removing 12,103 pounds of scrap, and sifting over 5,000 cubic yards of contaminated or potentially contaminated soil.

Remotely controlled UGVs significantly reduced the risk to human life by increasing the stand-off distance where UXO can be located and neutralized. In a typical range clearance operation, EOD personnel are deployed in teams of at least two people to clear the range of vegetation using chainsaws and handheld brush-cutters. This is extremely hazardous work as the vegetation can conceal potentially dangerous munitions. Using remotely controlled equipment, the operator can be safely located miles away.

AFRL Robotics personnel demonstrated a number of different types of robotically controlled equipment to determine which was most effective at each phase of the operations. The ARTS with brush cutter and tree shear attachments was found to be very effective in vegetation removal. The CAT 325 excavator with sifter bucket and electro-magnet with thumb attachments was used to locate and clear potential munitions items in very specific areas. MEC clearance was accomplished in the larger demonstration areas using the ARTS with power rake or rotor-tiller attachment and ARTS with Cherrington Beach Cleaner attachment. These operations were conducted in all types of inclement weather and were much more effective than using EOD personnel because the operators were able to perform their mission from a climatically controlled command center.

Collecting good data was critical to the success of this technology demonstration. AFRL Robotics personnel in conjunction with USACE collected electromagnetic (EM) data at a number of sites. The number of acres of vegetation cleared, cubic yards of dirt sifted, and quantities of munitions remedied were also recorded. Future research operations of this type will focus on collecting various other types of data to determine their affect on the success or failure of the mission. One of the factors not quantified during this operation was weather: “Does it make a difference if the temperature is -40ºF or 100ºF? What affect does rain or snow have on the operation?” These types of questions will be explored on future missions and the data collected to “quantitatively” provide the answers.

6.0 REFERENCES

[1] Department of Defense, "Unexploded Ordnance Response Technology and Cost", *A Report to Congress*, March 2001
[2] Impact Area Groundwater Study Program Website

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

ACC	Air Combat Command
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AP	Armor Piercing
ARTS	All-Purpose Remote Transport System
AURT	Automated UXO Response Technologies
BIP	Blow In Place
BLU	Bomb Live Unit
BRAC	Base Realignment and Closures
CAT	Caterpillar
CE	Civil Engineering
CIA	Central Impact Area
DDESB	Department of Defense Explosive Safety Board
DoD	Department of Defense
EM	Electromagnetic
EOD	Explosive Ordnance Disposal
FUDS	Formerly Used Defense Sites
HE	High Explosive
HEAT	High Explosive Anti-Tank
IAGWSP	Impact Area Groundwater Study Program
IBDSS	Intelligence Database Support System
IBDT	Integrated Base Defense Technologies
IDSS	Intelligence Database Support System
IED	Improvised Explosive Device
JAUS	Joint Architecture for Unmanned Systems
MACE	Mine Area Clearance Equipment
MCV	Mine Clearance Vehicle
MD	Munitions Debris
MEC	Munitions and Explosives of Concern
MMR	Massachusetts Military Reservation

REDCAR	Remote Detection, Challenge and Response
RRD	Range Related Debris
RSTA	Reconnaissance, Surveillance, and Target Acquisition
UGV	Unmanned Ground Vehicle
USACE	US Army Corp of Engineers
UXO	Unexploded Ordnance
XML	Extensible Markup Language